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Arctic Budget Study of Inter-member Variability using HIRHAM5 Ensemble Simulations

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Introduction

- chaotic and non-linear nature of atmospheric dynamics [1]
  - → RCMs are sensitive to their initial conditions (IC)
    - → generation of internal variability within RCMs
- **1)** investigation of internal variability = inter-member variance (IV) [2]
- **2)** estimation of diabatic and dynamical contribution leading to IV
  - → diagnostic potential temperature budget equation [3, 4]
- **3)** analysing the high IV event on 5th August 2012 at 06 UTC

Model: HIRHAM5

- hydrostatic regional atmospheric model
- driven by ERA-Interim
- integration area: Arctic
- ensemble with 20 simulations differing in their IC
  - initialisation time shifts about 6 hours for each run
  - analysed time period: 6th July to 30th September 2012
- runs without nudging

1) Inter-member Variability

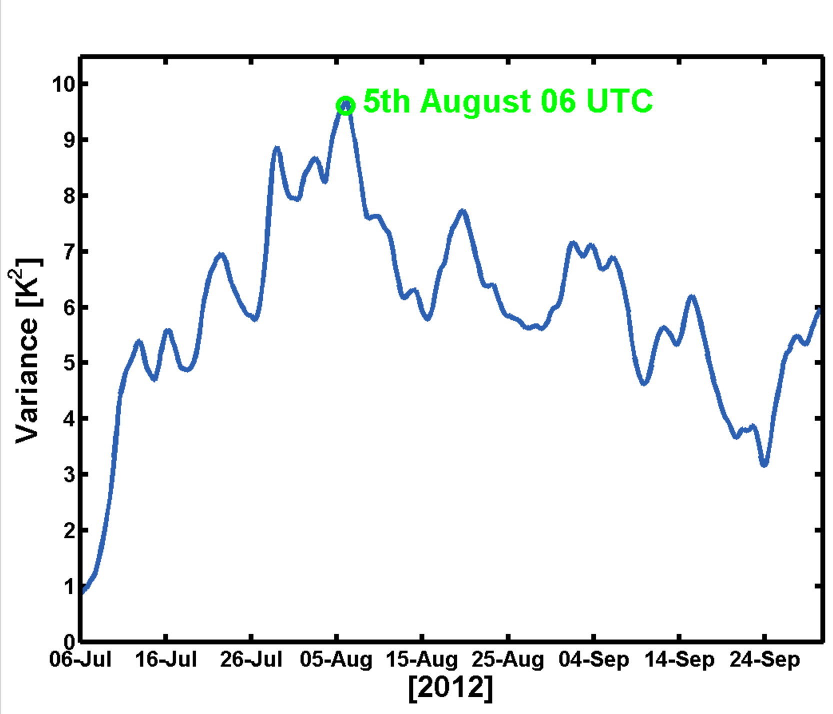


Fig. 1: Domain and vertical averaged potential temperature IV

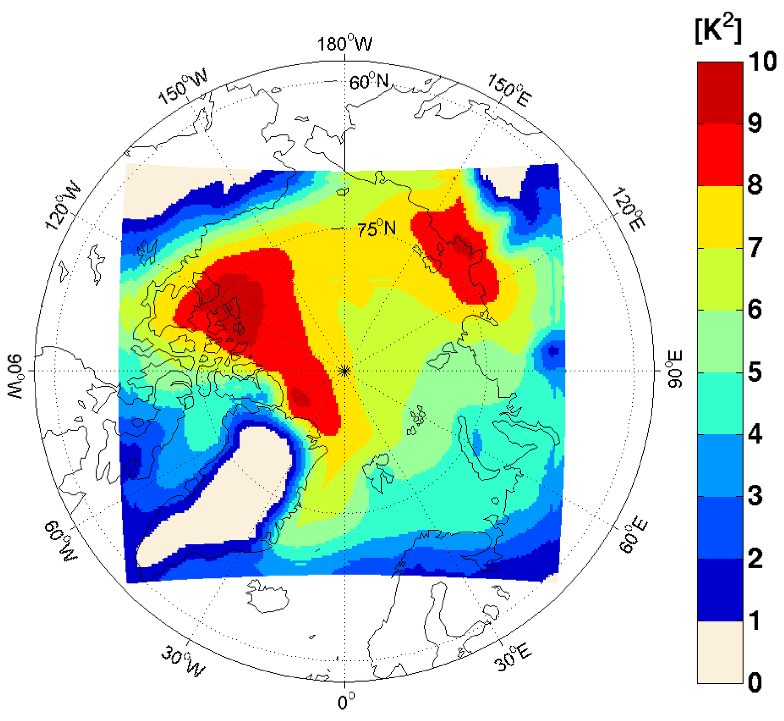


Fig. 2: Spatial distribution of the time averaged potential temperature IV at 925 hPa

2a) Diagnostic Potential Temperature Budget Equation

- IV is defined as the inter-member variance of the potential temperature $\boldsymbol{\theta}$ [3, 4] of the 20 ensemble-members $\boldsymbol{n}$

$$\sigma_\theta^2 \approx \langle\theta_n'^2\rangle \qquad \text{(Eq. 1)}$$

- emanating from the first law of thermodynamics for potential temperature and the mass-continuity equation in vertical pressure coordinates and applying the Reynolds decomposition
  - → the variable $\boldsymbol{\theta_n}$ split in the ensemble mean $\langle\boldsymbol{\theta_n}\rangle$ and the deviation from ensemble mean $\boldsymbol{\theta_n'}$

$$\theta_n = \langle\theta\rangle + \theta_n' \qquad \text{(Eq. 2)}$$

- results in a IV budget equation (Eq. 3) developed by [3, 4]

$$\frac{\partial \sigma_\theta^2}{\partial t} = -\vec{\nabla}\cdot\left(\langle\vec{V}\rangle\sigma_\theta^2\right) - \frac{\partial\left(\langle\omega\rangle\sigma_\theta^2\right)}{\partial p} - 2\left\langle\theta'_n\vec{V}'_n\right\rangle\cdot\vec{\nabla}\langle\theta\rangle - 2\left\langle\theta'_n\omega'_n\right\rangle\frac{\partial\langle\theta\rangle}{\partial p} + 2\left\langle\theta'_n J'_n\right\rangle - 2\left\langle\theta'_n\vec{\nabla}\cdot\left(\theta'_n\vec{V}'_n\right)\right\rangle - 2\left\langle\theta'_n\frac{\partial}{\partial p}\left(\theta'_n\omega'_n\right)\right\rangle \qquad \text{(Eq. 3)}$$

diagnostic tendency of potential temperature IV; A_h horizontal transport; A_v vertical transport; B_h horizontal baroclinicity; B_v vertical baroclinicity; C diabatic source/sink term; E_h horizontal third-order term; E_v vertical third-order term

2b) Contributions to IV

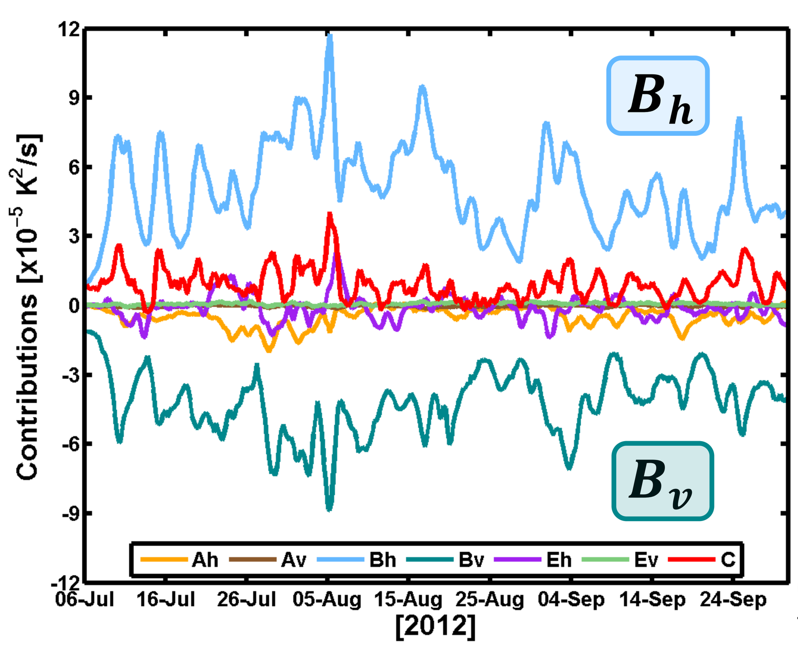


Fig. 3: Time evolution of the vertical and domain averaged contributions to potential temperature IV tendency

- $\boldsymbol{B_h}, \boldsymbol{B_v}$: baroclinic terms most important
- $\boldsymbol{A_h}$: small on domain average, but important for specific locations
- $\boldsymbol{C}$: small on domain and vertical average

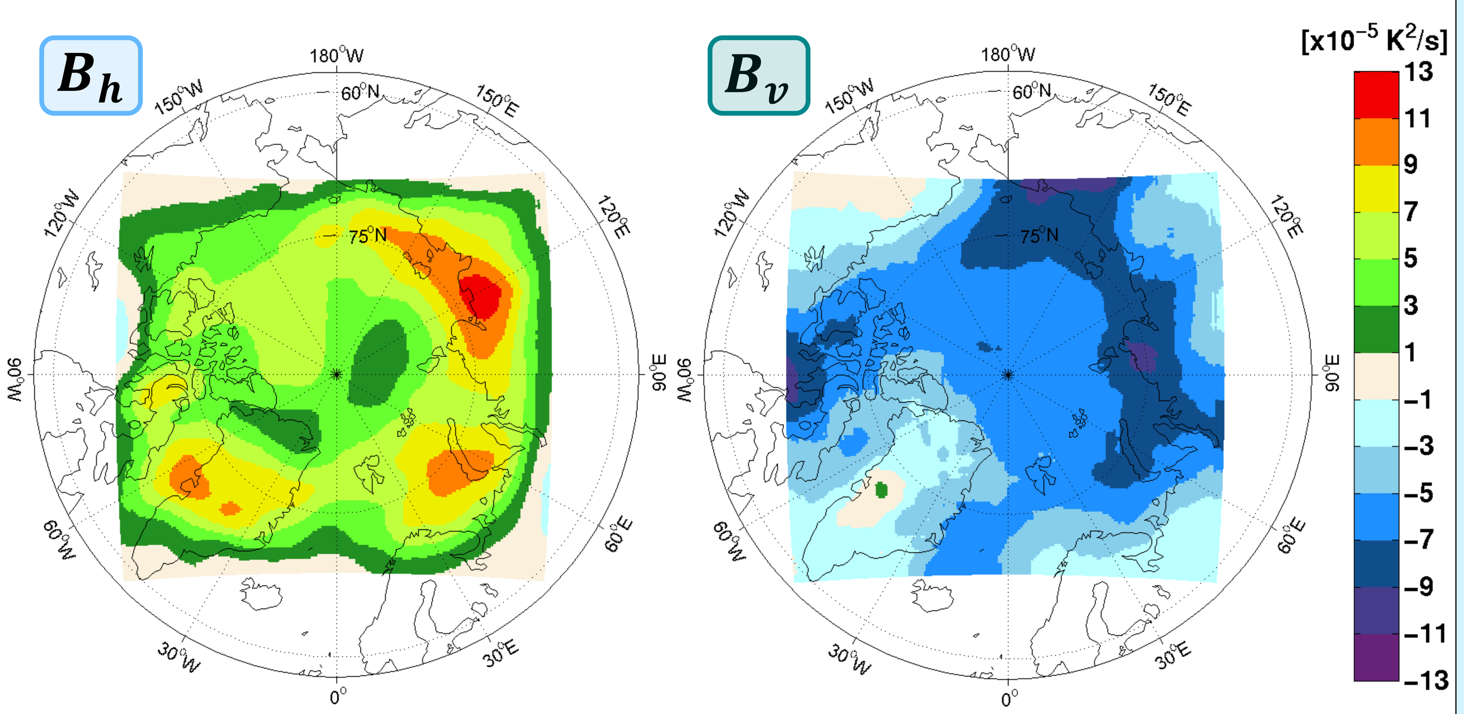
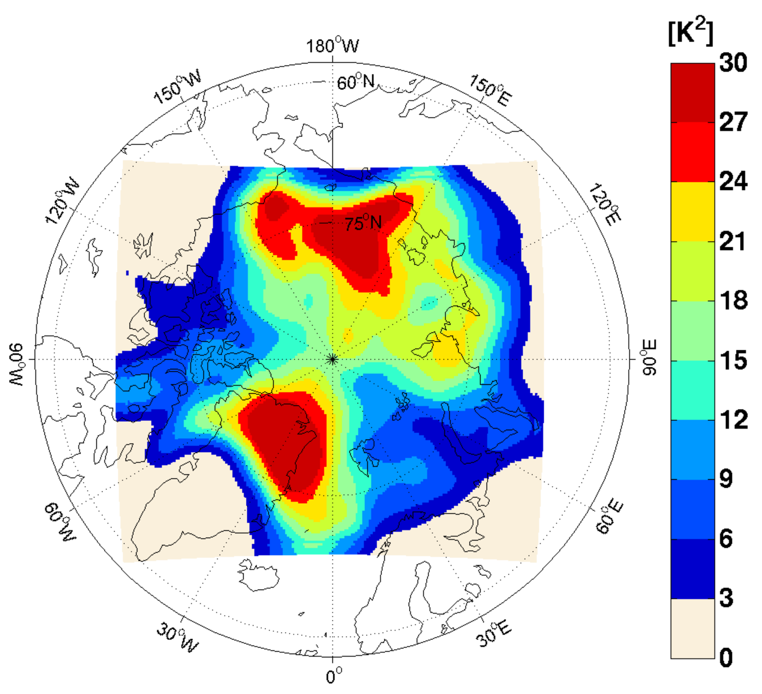


Fig. 4: Spatial distribution of the time averaged horizontal baroclinic term B_h (left) and vertical baroclinic term B_v (right) contributing to potential temperature IV tendency at 500 hPa

3) High IV event on 5th August 2012

- strongest IV event during summer 2012 on 5th August at 06 UTC
  - → strong baroclinic contribution ($\boldsymbol{B_h}$, $\boldsymbol{B_v}$) to IV tendency
    - → coinciding with the great Arctic cyclone in the beginning of August 2012 [5]
- great Arctic cyclone leads to an intense sea ice loss in East Siberian/Chukchi Sea
  - → strong diabatic contribution ($\boldsymbol{C}$) to IV tendency



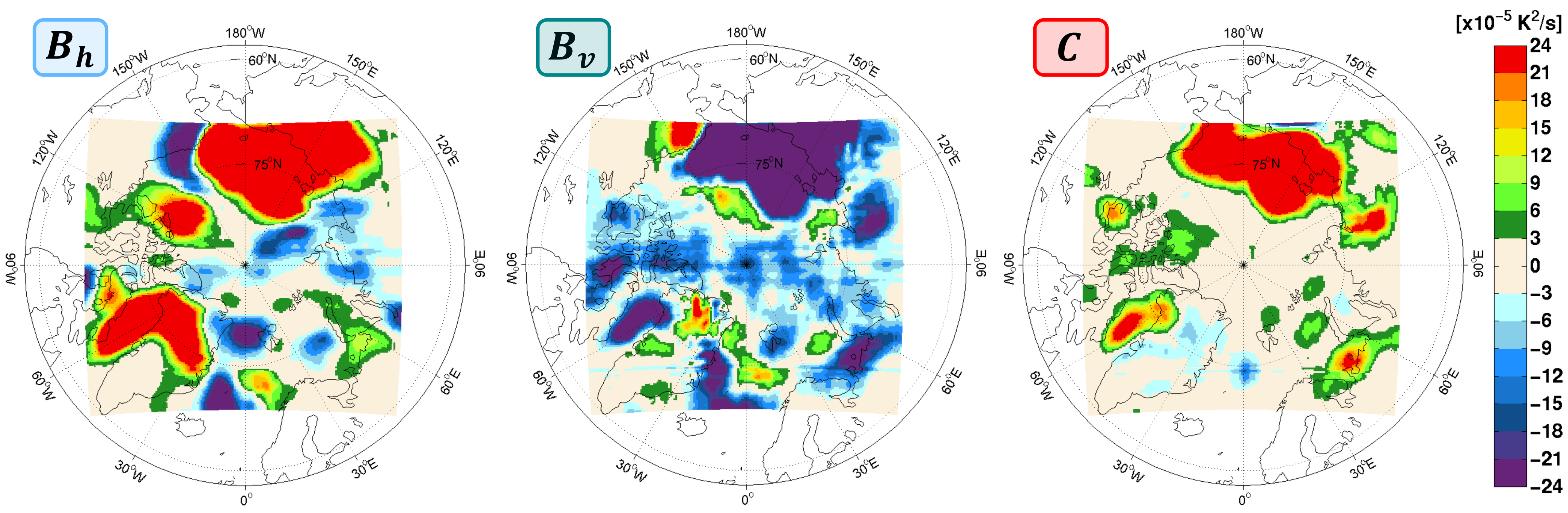


Fig. 5: Spatial distribution of the potential temperature IV (top) and the horizontal baroclinic term B_h (left), the vertical baroclinic term B_v (middle) and the diabatic source and sink term C (right) contributing to potential temperature IV tendency on 5th August 2012 at06 UTC at 500 hPa

Outlook

- application of budget study for other years (summer 2006, 2007, 2009)
- investigation of more high IV events
- comparison with the results obtained with the CRCM5 over the Arctic
  - → dependency of the IV and its contributions on the model structure and physical parameterisations

References

[1]: Lorenz, E.N., 1967. *The Nature and Theory of the General Circulation of the Atmosphere*. World Meteorl. Org., 161pp.

[2]: Alexandru, A. et al., 2007. *Internal Variability in Regional Climate Downscaling at the Seasonal Scale.* Mon Weather Rev. 135, 3221-3238

[3] Nikiema, O. and Laprise, R., 2010. *Diagnostic budget study of the internal variability in ensemble simulations of the Canadian RCM*. Clim. Dyn. 36, 2313-2337

[4]: Nikiema, O. and Laprise, R., 2011. *Budget study of the internal variability in ensemble simulations of the Canadian RCM at the seasonal scale.* J. Geophys. Res. Atmos. 116(D16112)

[5]: Zhang, J. et al., 2013. *The impact of an intense summer cyclone on 2012 Arctic sea ice retreat*. Geophys. Res. Lett. 40, 720-726